

AL/OE-TR-1996-0002



EFFECT OF HAZE IN ADVANCED LASER EYE PROTECTION VISORS ON CONTRAST ACUITY

Robert N. Kang, Major, USAF
Connie S. LaPage, Master Sergeant, USAF
Steven R. Cora, Technical Sergeant, USAF

OCCUPATIONAL AND ENVIRONMENTAL HEALTH DIRECTORATE
Optical Radiation Division
8111 18th Street
Brooks Air Force Base, TX 78235-5215

DTIC QUALITY INSPECTED 4

January 1996

Final Technical Report for the Period February to October 1995.

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ROBERT M. CARTLEDGE, Lt Col, USAF, BSC
Chief, Optical Radiation Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 1996	3. REPORT TYPE AND DATES COVERED Final - February - October 1995	
4. TITLE AND SUBTITLE Effect of Haze in Advanced Laser Eye Protection Visors on Contrast Acuity			5. FUNDING NUMBERS PE - 63231F PR - 2830 TA - 01 WU - 14	
6. AUTHOR(S) Robert Kang, Connie S. LaPage, Steven R. Cora				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Armstrong Laboratory Occupational and Environmental Health Directorate 8111 18th Street Brooks Air Force Base TX 78235-5215			10. SPONSORING/MONITORING AL/OE-TR-1996-0002	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Laboratory tests were conducted to evaluate the effects of haze in FV-6MR and FV-7 advanced laser eye protection (ALEP) visors on vision. Preliminary results from early operational assessment (EOA) flight tests with the FV-6MR (night use) and FV-7 (day use) visors suggested that the current USAF standards for haze may not adequately predict either the user acceptance or mission compatibility. In addition to the ALEP visors, the standard USAF sun and clear visors were also tested for comparison purposes. A contrast acuity test served as the measure of visual performance. The results suggest that the effects of haze in the ALEP visors on vision were primarily on low contrast targets, decreasing visual acuity. Presence of a glare source, simulating the sun near the line of sight, enhanced the effects of haze, further decreasing visual performance suggest that higher luminance transmittance mounted visors performed better. Overall, however, the results suggest that the ALEP visors and the standard USAF sun visor performed similarly, indicating that neither the dye technology used in ALEP visors nor the selective filtering of visual spectrum for laser protection is unique. It is recommended that the haze requirement for all ALEP visors not be relaxed from the current USAF helmet visor standard of 2.0%.				
14. SUBJECT TERMS ALEP; haze; performance; visors			15. NUMBER OF PAGES 22	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89) Prescribed by ANSI Std Z-39-18
298-102 COMPUTER GENERATED

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INTRODUCTION

The issue addressed in this report is the optical haze in the Advanced Laser Eye Protection (ALEP) visors as a possible problem in user acceptance and mission compatibility. The purpose of the study was to examine the possible effects of haze and distortion in the ALEP visors on visual performance. The results from early operational assessment (EOA) flight tests with the ALEP visors suggested that the current USAF standards for haze and distortion may not adequately predict either the user acceptance or mission compatibility. The present study was conducted using the ALEP visors including the FV-6MR (night use) and the FV-7 (day use) visors as well as the standard USAF sun and clear visors.

Haze is defined, by the National Bureau of Standards (NBS), as the ratio of the scattered light to the total light that is transmitted through the transparency of interest. Haze results from optical imperfections, such as scratches on the surfaces or striations in the material. Haze could also result from the use of absorptive dyes in the sun and ALEP visors. A Haze measurement standard has been established by the American Society for Testing and Materials (ASTM). The Gardner Hazemeter is a specific device designed to measure haze based on this standard (ASTM D1003-92). Currently, the USAF adheres to the ASTM standard (MIL-V-43511C).

Military aviation requirements dictate high optical quality transparencies. For helmet visors, the current USAF specification for haze is 2.0%. The basis for this specification is, however, not clear. The current specification was based on manufacturing capabilities and not on visual performance requirement (Grether, 1973). From an optical stand point, haze is a relatively simple measure. The effect of haze on visual performance, however, appears to be more complex and cannot easily be correlated with the optical measure of haze. In particular, the effects of haze under different ambient light conditions and in the presence of a glare source such as the sun are not well understood. The effects of haze on vision is known to depend largely on ambient light conditions.

In the past, efforts to establish a new haze specification which is based on visual performance has been unsuccessful, partly because of the lack of data correlating optical haze in military transparencies and visual performance, and partly because of the subjective nature of what aircrew call "haze". In addition, the combined effects of various optical components in an aircraft such as the windscreen, canopy, heads-up display (HUD), and various helmet visors, including the ALEP visors, further complicate the problem. One purpose of this study is to understand this subjective nature of "haze" in helmet visors by systematically relating to measures of human performance.

When looking through a canopy, for example, the visual effects of haze can be characterized as 1) the loss of scene contrast from light scattering into the line of sight (veiling glare), 2) the loss of resolution, and 3) a reduction in the luminance transmittance (Task and Genco, 1985; Gish and Sheehy, 1993). The light scattering effect is largely

dependent on the nature and amount of light illuminating the transparency and has the greatest effect on low contrast targets. A glare source, such as the sun or a laser beam, amplifies the effect of light scattering from haze and distortion. The loss of resolution stems from the fact that haze has a greater effect on fine-detail information (high spatial frequency) relative to low spatial frequency information.

In most conditions, the reduction in luminance transmittance due to optical haze is relatively quite low and may normally be considered an insignificant factor affecting vision performance. However, in a cockpit environment, the loss in luminance transmittance may be more significant because of the multiple of optical material between the outside environment and the aircrew. Windscreen/canopy and heads-up display (HUD) each reduce luminance transmittance (due to tints in the material or through reflections at surfaces), and the effect is multiplicative. Therefore, the amount of light available to the aircrew wearing sun or ALEP visors, which have photopic luminance transmittance (PLT) values in 10-15% range, may be quite low. The additive loss of luminance transmittance due to haze in the windscreen/canopy, HUD, and helmet visors makes the situation worse and may, in fact, lower it to the level that is unacceptable to the aircrew under some flight conditions. Typically, windscreens and canopies used in military aircraft have higher haze values when compared to helmet visors (Task and Genco, 1985).

In the present study, a contrast acuity test served as the measure of visual performance. ALEP visors were selected to include a wide range of haze and photopic luminance transmittance (PLT) values. The purpose of the study was to use ALEP visors which were used in EOA flight tests so that laboratory visual performance results could be compared to aircrew feedback results. In addition, the standard sun and clear helmet visors were included in this study so that visual performance data for the ALEP visors could be compared to those visors aircrew were already familiar with. Many of the comments from EOA flight tests were comparative in nature (e.g., comparing the ALEP visors to the sun visor). A spot light was used to simulate sun induced glare. This was to address another finding from the EOA results which suggested that the haze in ALEP visors had a greater effect on aircrew during setting sun induced glare. This glare source was transmitted through a F-15 windscreen. Conclusions based on these results served as the basis for the new ALEP helmet visor haze requirement recommendation.

METHODS

Participants

Eight subjects, six male and two female, range 22 to 45 years, participated in this study. All subjects were volunteers. As the study was conducted in two parts, there were two groups of six subjects with four subjects participating in both parts, average age 31.0 and 30.8 years, respectively. All subjects had 20/20 or better visual acuity, with

correction when needed, and all the subjects met the Air Force vision requirements of Flying Class III Physical examination per AFI 48-123.

Apparatus

Testing was conducted in a room where illumination was provided by recessed ceiling fluorescent lights. The light level measured approximately 890 lux at the subject's eye, a low photopic condition. Binocular distance contrast acuity at 10-ft was measured using five Regan contrast charts (96, 50, 25, 11, and 4%) following standard Regan chart procedures. To overcome the possible familiarization with the letters of the contrast charts, two sets of Regan charts with different lettering schemes were used. The luminance of the charts were 104 cd/m^2 , measured either through or without the F-15 windscreen which was placed between the subject and the acuity charts. The F-15 windscreen was placed at proper the height and distance from the subjects, as would be from aircrew in a real F-15 aircraft cockpit. The Part 1 of the study was conducted with the windscreen in place while the Part 2 was conducted without the windscreen but followed essentially identical procedures.

A 575 W fresnel spot light system, designed for use in the TV/Film industry, was used as a glare source to simulate the sun. The fresnel light (Altman model 575SE with metal halide bulb, 5600 °K color temperature, 5 inch beam diameter) was located 10-ft in distance from the subject, at the height of the subject's eye level. At the subject's eye, the output of the fresnel light, measured either through the F-15 windscreen or without the windscreen, was approximately 1300 lux, a moderate level which was just enough to cause slight discomfort to look at directly with a naked eye. The output of the fresnel light was adjusted with gelatin neutral density filters.

Six visors were tested; one standard USAF sun visor, one standard USAF clear visor, two FV-6MR (night use ALEP), and two FV-7 (day use ALEP) visors. In Part 1 of the study, only one FV-6MR visor was used. The second FV-6MR visor became available later and was added to the Part 2 of the study. The two FV-7 visors were tested in both the Part 1 and Part 2 of the study. The visors were selected to provide a range of photopic luminance transmittance (PLT) and haze values. The test visors were measured for haze with a Gardner Hazemeter model 211 before the study. The visors were also tested for distortion, optical power, and prism using an Ann-Arbor (Ronchi) distortion test and a lensometer. The PLT of the visors were measured with a Varian Cary Spectrophotometer. All the tests on the visors were done on nine locations according to MIL-V-43511C, except the Varian Cary Spectrophotometer measurement which was done on two center locations only. The visors were mounted on an aircrew helmet (HGU-55/P) in a standard fashion

Procedure

After an initial familiarization with the experimental set up and the tasks, subjects were seated behind the F-15 windscreen wearing an aircrew helmet. Contrast acuity measurements were made both with and without visors. Following a pre-established random order, a visor was selected and attached to the helmet the subject was wearing. The subject then adapted with the visor for 3 minutes, which proved to be a time sufficient for acuity measurement. After adaptation, measurements were taken using 5 contrast charts, in either ascending or descending order of the contrast of letters. Two sets of Regan charts were used alternatively. On each chart, subjects were asked to read the smallest line of letters they could read. Contrast acuity measurements were made both without and with off-axis glare (5°, 10° and 20° in horizontal axis). In Part 1, each subject was tested with five visors and with three glare conditions with the windscreen in place. In Part 2, each subject was tested with all six visors but with the glare only at 20° in horizontal axis and without the windscreen in place. Raw acuity data were converted to log minimum angle of resolution (MAR) for analysis.

RESULTS

Physical measurements

The results of haze, PLT, and distortion measurements for the six helmet visors used in the present study are presented in Table 1. Optical power and prism data are not presented as all the visors were essentially identical. All the visors met the current USAF requirements for optical power and prism except for the FV-7 #2 visor which had one failing distortion rating. The failing rating was at the lower center portion on the left side of the visor. This location is not in the line of sight for distance viewing and, thus for the purposes of the study, this failing rating was assumed to have no significant effect on the outcome.

TABLE 1. OPTICAL PROPERTIES OF THE VISORS

VISORS	Photopic Luminance Transmittance (mean \pm SD)	Haze (mean \pm SD)	Distortion* (mean/range of rating)
CLEAR	90.1 \pm 0.1%	0.1 \pm 0.1%	P1/P1, all positions
SUN	13.1 \pm 0.7 %	0.0 \pm 0.0%	P1/P1, all positions
FV-6 MR #1	32.2 \pm 0.6%	0.9 \pm 0.1%	P1.6/P1-P3
FV-6 MR #2	32.8 \pm 0.6%	2.6 \pm 0.1%	P1.6/P11-P3
FV-7 #1	10.0 \pm 0.5%	1.0 \pm 0.1%	P2.3/P1-P3
FV-7 #2	13.6 \pm 0.2%	3.2 \pm 0.1%	P3.4/P1-F6

* Scored on 1-9 rating scale at 9 locations per visor per MIL-V-43511C. P1 to P5 are passing scores and F6 to F9 are failing scores.

Effects of Visors

Data from Part 1 and 2 were analyzed separately. Contrast acuity data from Part 1 are plotted in Figure 1(A). Data from the no visor condition are not plotted as they did not differ from the clear visor data. The average log MAR (minimum angle of resolution) and the equivalent Snellen acuity scores for 6 subjects are shown. As can be seen, all the visors reduced visual acuity across the contrast range when compared to the clear visor. For example, for the sun visor, the acuity was reduced from approximately 20/20 for the 96% contrast of letters to approximately 20/70 for the 4% contrast of letters. Comparison of the test visors suggest that the reduction in acuity largely depended on photopic luminance transmittance (PLT) across most of the contrast range, except for the 4% contrast of letters. Thus, the FV-6MR visor which had a higher PLT compared to the sun or FV-7 visors performed better than both visors. The results at the 4% contrast of letters suggest that haze had a greater effect in acuity than PLT at this low contrast level.

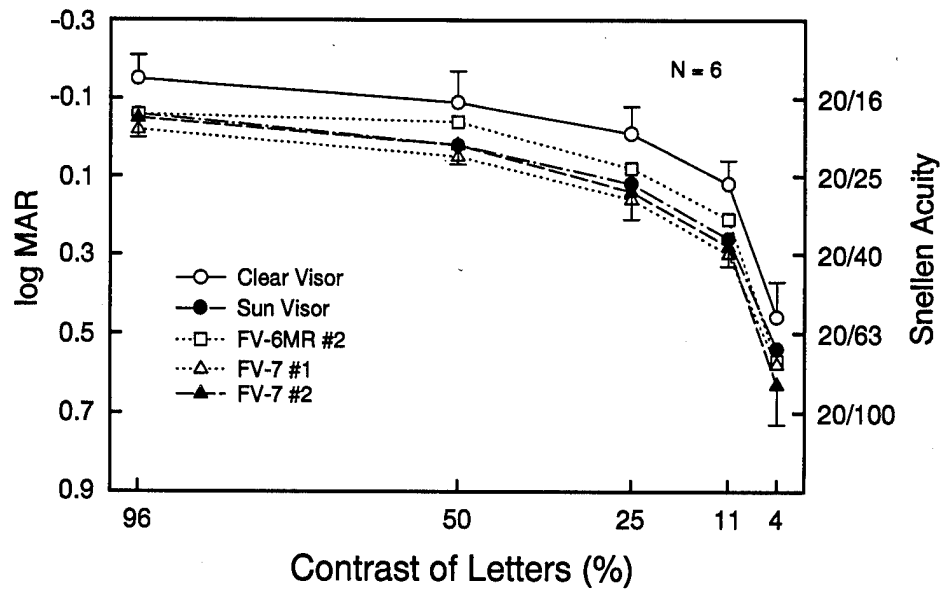
The effects of haze will be discussed in detail later. The data from Part 2 (without windscreen) are shown in Figure 1(B). The similar effect of contrast of letters for all the test visors can be seen. Comparison of Figure 1(A) and Fig 1(B) suggest that there were no significant effects of the windscreen on the contrast acuity for the conditions of this study.

A repeated measures analysis of variance (ANOVA) was performed on the data for the effects of VISOR, GLARE, and CONTRAST as well as for interactions. Again, the results of Part 1 and 2 were analyzed separately and are shown separately in Tables 2 and 3, respectively. As can be seen in Tables 2 and 3, the main effect of VISOR and the interaction of VISOR and CONTRAST were significant for the conditions of Parts 1 and 2 of this study.

TABLE 2. RESULTS OF ANALYSIS OF VARIANCE:
PART 1. WINDSCREEN IN PLACE.

SOURCE	DF	SS	MS	F	p
VISOR (V)	4	1.29	.32	67.42	0.00
CONTRAST (C)	4	44.05	11.1	1179.00	0.00
V*C	16	.09	.01	2.53	.003
GLARE (G)	3	4.27	1.42	63.63	.000
V*G	12	.11	.01	2.53	.009
C*G	12	1.53	.13	13.65	0.00
V*C*G	48	.15	.00	.89	.685

(A) No Glare/Windscreen



(B) No Glare/No Windscreen

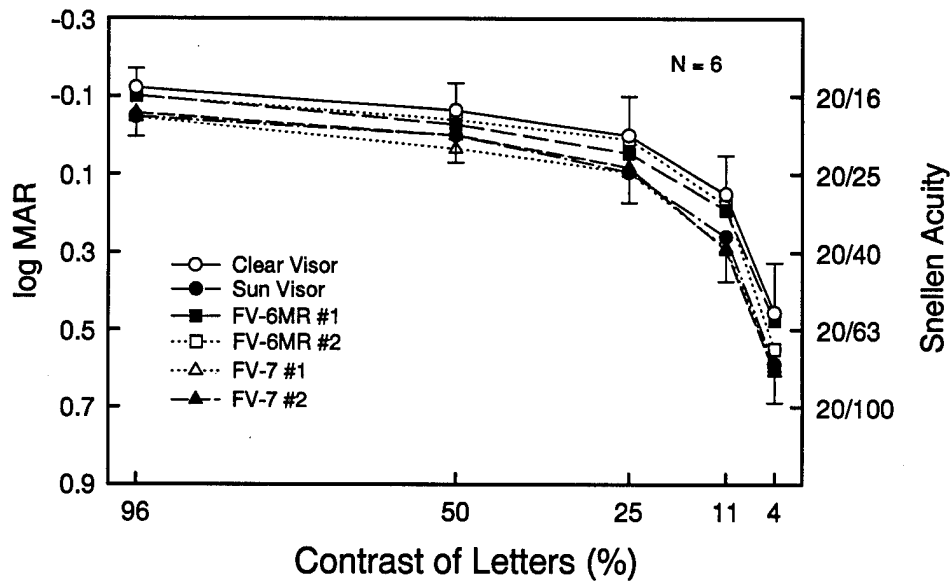


Figure 1. Contrast acuity for all visor with windscreen (A) and without windscreen

TABLE 3. RESULTS OF ANALYSIS OF VARIANCE:
PART 2. NO WINDSCREEN.

SOURCE	DF	SS	MS	F	P
VISOR (V)	5	.70	.14	34.36	.000
CONTRAST (C)	4	20.50	5.12	777.32	.000
V*C	20	.07	.00	1.68	.049
GLARE(G)	1	.02	.02	1.73	.246
V*G	5	.02	.00	1.60	.198
C*G	4	.09	.02	6.60	.001
V*C*G	20	.07	.00	1.96	.016

Since the primary purpose of this study was to evaluate and compare the individual visors, in addition to the above analysis, pair-wise analysis of variance for the test visors were also performed. The results are summarized in Table 4 and Table 5 for Part 1 and 2 of the study, respectively. Overall, the results suggest that PLT may have had greater effect on acuity than haze and that even haze difference as large as 3% may not have had significant effect on acuity. The effect of PLT may be seen in the comparisons of the two FV-7 and sun visors. When compared to each other, the FV-7 visors were found to be significantly different for both the conditions of with the windscreen (Table 4, $p = 0.02$) and without (Table 5, $p = 0.03$). However, comparisons of the two FV-7 visors with the sun visor were not consistent. The FV-7 #1 visor (10.0% PLT and 1.0% haze) was different ($p = 0.001$) than the sun visor while the FV-7 #2 visor (13.6% PLT and 3.2% haze) was not ($p = 0.31$). The sun visors had 13.1% PLT and 0% haze (Table 1). Thus, the results suggest that the PLT difference, even as small as 3%, may have had significant effect on contrast acuity, while the haze difference as large as 3.2% may not have had significant effect.

TABLE 4. P-VALUES FROM PAIR-WISE ANOVA FOR VISORS IN PART 1:
WINDSCREEN IN PLACE.

SOURCE	1v2*	1v4	1v5	1v6	2v4	2v5	2v6	4v5	4v6	5v6
VISOR (V)	.000	.003	.000	.000	.005	.001	.306	.000	.000	.02
CONTRAST (C)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
V*C	.000	.331	.003	.142	.012	.926	.372	.027	.281	.713
GLARE (G)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
V*G	.185	.044	.194	.062	.035	.654	.067	.059	.262	.09
C*G	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
V*C*G	.985	.065	.619	.130	.743	.692	.554	.928	.12	.869

* V1-CLEAR V2-SUN V3-FV-6 MR #1 V4-FV-6 MR #2 V5-FV-7 #1 V6-FV-7 #2

TABLE 5. P-VALUES FROM PAIR-WISE ANOVA FOR VISORS IN PART 2: NO WINDSCREEN.

SOURCE	1v2*	1v3	1v4	1v5	1v6	2v3	2v4	2v5	2v6	3v4	3v5	3v6	4v5	4v6	5v6
VISOR (V)	.003	.026	.002	.000	.002	.001	.011	.088	.78	.138	.001	.000	.01	.000	.03
CONTRAST (C)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
V*C	.008	.229	.178	.038	.289	.117	.204	.130	.195	.541	.592	.164	.968	.480	.467
GLARE (G)	.721	.937	.218	.415	.802	.359	.086	.175	.65	.107	.820	.174	.259	.122	.433
V*G	.435	.625	.182	.277	.850	.541	.183	.442	.234	.137	.606	.392	.045	.575	.102
C*G	.006	.206	.001	.008	.046	.070	.000	.002	.065	.045	.249	.194	.012	.000	.207
V*C*G	.134	.329	.207	.653	.399	.174	.136	.854	.012	.003	.673	.337	.005	.409	.066

* V1-CLEAR V2-SUN V3-FV-6 MR #1 V4-FV-6 MR #2 V5-FV-7 #1 V6-FV-7 #2

The effect of haze may also be seen in comparison of the two FV-6MR visors where PLT values are somewhat matched (32.2% vs. 32.8%, FV-6MR #1 and #2 respectively). Despite the 1.7% difference in haze (0.9% vs. 2.6%, FV-6MR #1 and #2 respectively), the two FV-6MR visors were not different from each other ($p = 0.138$) (Table 5). However, both the FV-6MR visors were different compared to the other visors. The FV-6MR #2 visor in Part 1 of the study was found to be significantly different when compared to either of the two FV-7 visors or to the sun visor (Table 4). In Part 2, both the FV-6MR #1 and #2 were found to be significantly different when compared to the sun visor or to the FV-7 visors (Table 5). Thus, the results suggest that PLT values are the main reason for significant differences between visors.

Effects of Glare

The contrast acuity data for the three off-axis glare angle conditions from Part 1 are plotted in Figure 2. As expected, the glare reduced the contrast acuity as a function of off-axis angle. However, the effects of glare were limited primarily to the lower contrast of letters. As can be seen Figure 2, using the FV-7 #1 visor as an example, the acuity for the 11% contrast of letters for the 5°, 10°, and 20° glare conditions were approximately 20/100, 20/60, and 20/40, respectively. For the 4% contrast of letters, the glare at 5° and 10° reduced the acuity below 20/100 meaning that the letters simply could not be read. For the 96 and 50% contrast of letters, the change in acuity was minimal for all three glare conditions, and similar to the no glare condition (Figure 1).

The results of ANOVA show that, in Part 1, the main effect of GLARE as well as the two-way interactions of the GLARE with VISOR and CONTRAST were significant (Table 2). In Part 2, however, neither the main effect of GLARE nor the interactions involving the GLARE are significant, probably reflecting the fact there was only one glare condition (at 20° off-axis) compared to the three glare conditions in Part 1 of the study. Glare for the 3 glare conditions had the least effect at 20° off axis (Figure 2).

Overall, the results of PLT matched visor comparisons suggest that the effects of glare on haze in the visors tested were minimal. The results of the pair-wise ANOVA

comparisons summarized in Table 4 show that the main effect of GLARE was significant between the FV-7 visors ($p = 0.00$), but the interaction of VISOR and GLARE was not ($p = 0.09$). Also, the two FV-7 visors, despite the difference in haze (1.0% vs. 3.2%), did not show a significant VISOR and GLARE interaction when compared individually to either the sun visor or to the FV-6MR #2 visor. Similarly, the difference in the haze values between the FV-6MR visors (0.9% vs. 2.6%) did not interact significantly with glare (Table 5). Both the main effect of GLARE and the interaction of VISOR and GLARE were not significant for the two FV-6MR visors.

Comparison of the FV-6MR #2 visor with the sun and the FV-7 visors in the results from Part 1 suggests, however, that glare and haze may have interacted. The FV-6MR #2 visor (2.6% haze), when compared to the sun visors (0% haze) was significantly different for both the main effect of GLARE ($p = 0.00$) and the interaction of VISOR and GLARE ($p = 0.04$) (Table 4). However, when compared to the two FV-7 visors which had similar PLT to the sun visor but higher (1.0% and 3.2%) haze, the FV-6MR #2 visor was significantly different only for the main effect of GLARE but not for the interaction of the VISOR and GLARE. The fact that FV-6MR #2 visor differed from the sun visor for the effects of glare while the two FV-7 visors did not may suggest that the interaction of glare and haze may be more noticeable in visors with different PLT values.

Effects of Windscreen

The effects of the F-15 windscreen on contrast acuity were minimal for the conditions of this study and are shown in Figure 1 and Figure 3. As can be seen in both Figure 1 and 3, the F-15 windscreen did not affect the contrast acuity significantly for all the visors across the contrast of letters, even in the presence of glare at 20°. A between subjects analysis of variance was performed on the data from Part 1 and Part 2, without the additional glare conditions in Part 1 of 5° and 10° and without the FV-6MR #1 data in Part 2. The results were not significant for either the main effects of the windscreen or interactions involving the windscreen. Pair-wise ANOVA of the visors also yielded no significant results. Given the fact that the haze in the F-15 windscreen measured approximately 5%, the results suggest that the visual effects of haze might be greater in helmet visors which are much closer to the eyes.

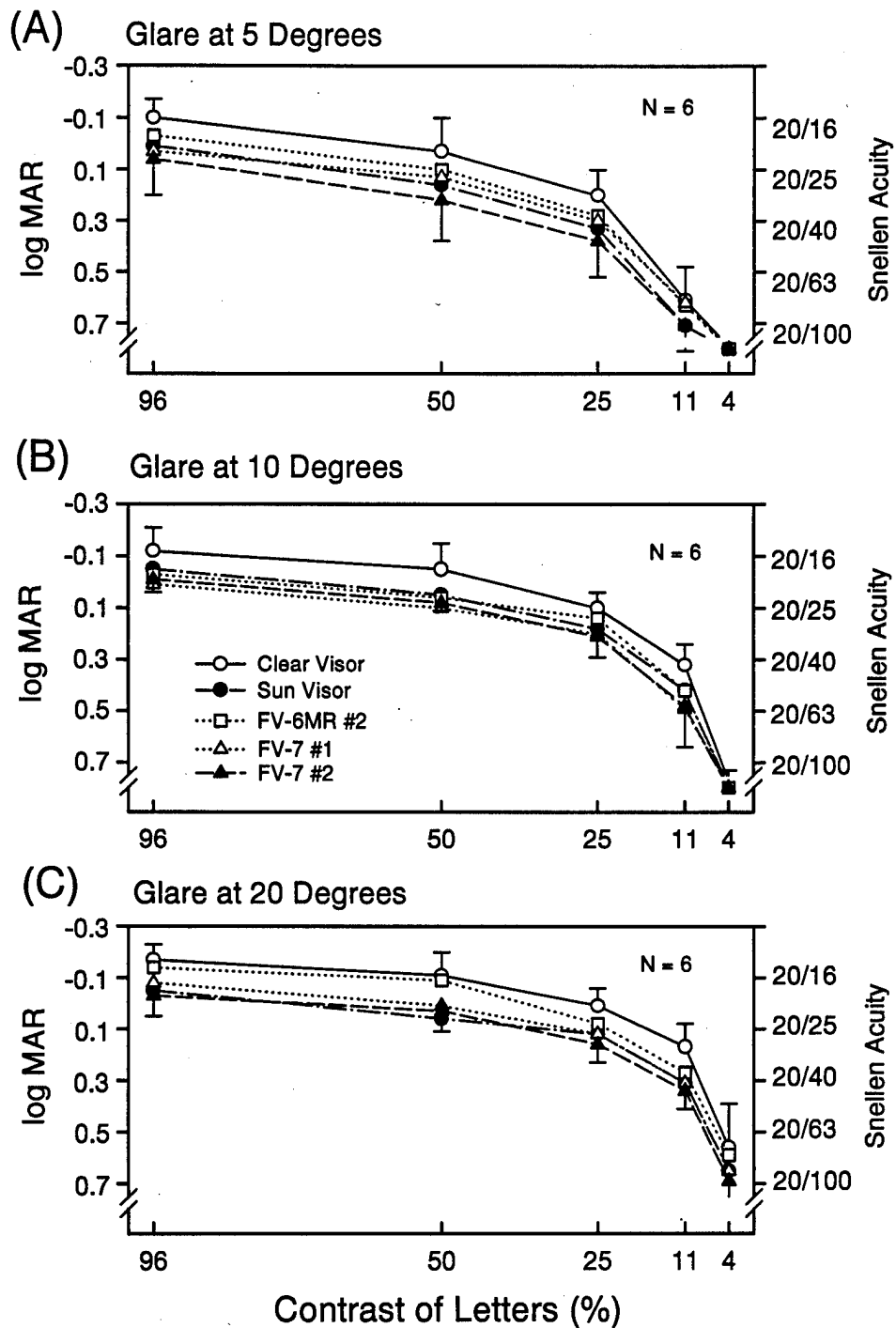
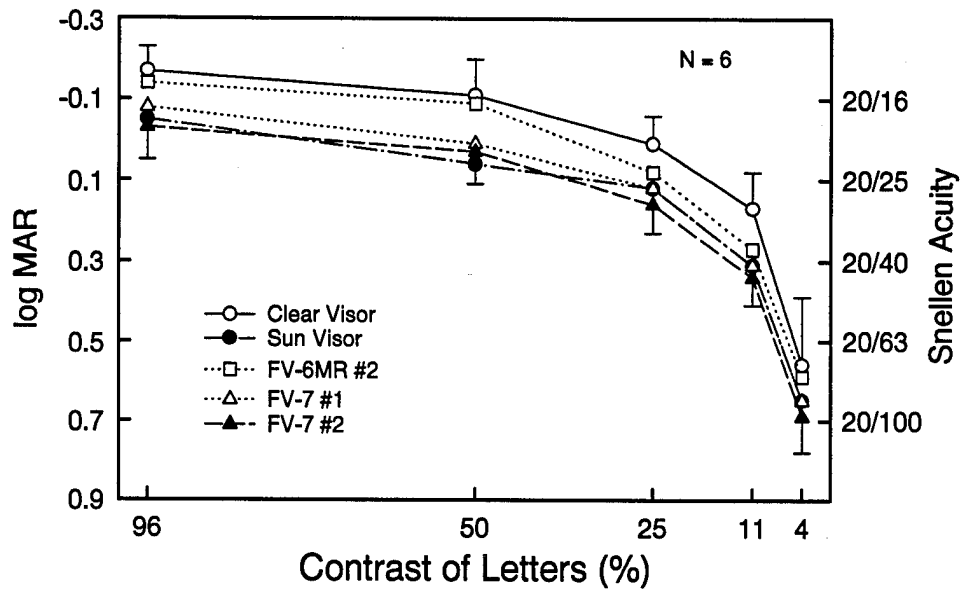


Figure 2. Contrast acuity for all visors with glare at 5° (A), 10° (B), and 20° (C) off-axis.

(A) Glare at 20 Degrees/Windscreen



(B) Glare at 20 Degrees/No Windscreen

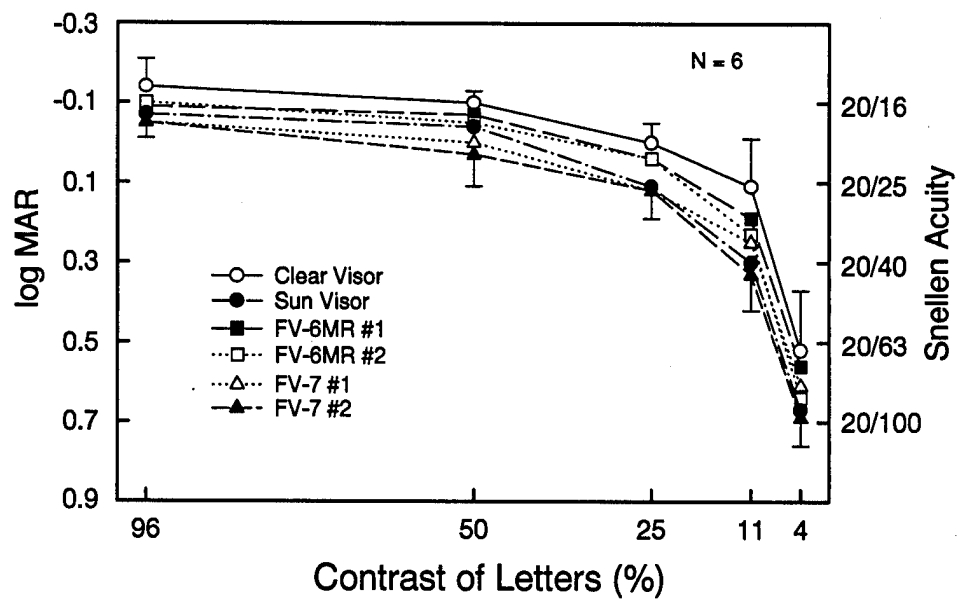


Figure 3. Contrast acuity with glare at 20° off-axis for with windscreen (A) and without windscreen (B).

DISCUSSION

For the conditions of the present study, it was not possible to establish a systematic relationship for the haze in aircrew helmet visors to contrast acuity. There may be two reasons for this. One reason might be that the study was designed to test available visors with a range of PLT and haze values rather than testing systematically varied range of haze samples. As mentioned above, the reason for this was to test what aviators subjectively call "haze" rather than testing artificially created "haze" optical samples. The other reason might be that the effects of PLT on contrast acuity were found to be greater than the effect of haze. However, while the results do not represent a robust phenomenon, when taken together, they do suggest that haze in helmet visors may reduce contrast acuity for the lower contrast targets.

The suggestion that PLT may have had greater effect on visual performance of helmet visors than haze may be observed in the result that under most conditions the two FV-7 visors and the sun visor as a group (PLT, 10-13%) performed worse compared to the FV-6MR visors (PLT, 32%) which in turn performed worse than the clear visor (PLT, 90%). Thus, the FV-6MR #2 visor which had a haze value of 2.6%, well above the current USAF 2.0% specification, reduced the contrast acuity more when compared to the sun visor which had no measurable haze but a lower PLT value. Also, the contrast acuity with the FV-7 #2 visor (PLT/Haze; 13.6%/3.2%) did not differ compared to the sun visor (13.1 %/0.0%), while it did when compared to the FV-7 #1 visor (10.0%/1.0%). Similarly, for the two FV-6MR visors no significant differences were observed between the FV-6MR #1 visor (32.1%/0.9%) and the FV-6MR #2 visor (32.8%/2.6%). Thus, the results indicate that the PLT and haze in our visors may have interacted together but that the effects of PLT on contrast acuity was greater.

The effects of haze for low contrast letters may be best observed in the comparisons between the FV-6MR #2 and the sun visor and between the two FV-7 visors. For example, Figure 1(A) shows that the acuity at the 4% contrast of letters were lower for the FV-6MR #2 visor (higher haze) compared to the sun visor despite the fact that the FV-6MR #2 visor had a much higher PLT value. Also, although the differences were rather small, comparison of the two FV-7 visors in Figure 1(A) shows that the acuity for the FV-7 #2 (higher haze) were lower for the 4% contrast of letters compared to the FV-7 #1 visor. In fact, it can be seen that the acuity for the FV-7 #2 visor is better for the higher contrast of letters (96, 50, and 25%). The FV-7 #2 visor had a higher PLT (13.6%) compared to the FV-7 #1 visor (10.0%).

The presence of glare appears to have enhanced the effects of haze for the lower contrast of letters. For example, in the presence of glare at 5°, the FV-7 #2 (higher haze) reduced acuity more across the contrast of letters compared to the FV-7 #1 such that the differences between the two may be seen not only at the 4% contrast of letters but also at the 50% contrast of letters [Figure 2(A)]. Overall, however, the effects of glare were minimal across the PLT and haze ranges in the helmet visors tested.

CONCLUSION

The lack of a robust relationship between percent haze and visual performance makes it difficult to recommend/establish a new specification for haze in the ALEP visors. Clearly, further studies are necessary to examine the interactions of haze and luminance transmittance. However, a number of conclusions may be drawn from our results. Overall, the results of the present study suggest that 1) the reduction in the contrast acuity with the ALEP visors, across a large range of contrast (96 to 4%), is similar to what is observed with the sun visor, 2) the presence of glare in the field of view reduced the contrast acuity primarily at lower contrast of letters in a highly angular dependent manner, and 3) the haze in the ALEP visors may reduce the contrast acuity for the operationally more relevant low contrast targets and that the glare at very close angles to the line of sight may make the problem of haze worse. The effects of haze, however, appears to be less significant compared to the effects of luminance transmittance, which overall had a greater effect on visual performance.

To maximize the protection from laser threats afforded to aircrew members while minimizing the visual effects from the ALEP visors, it is clear that more overall luminance transmittance, less haze, and less distortion are all needed. Ultimately, however, there needs to be a balance between the protection and visual performance. As an example, our results show that, for the 25% contrast of letters condition, the contrast acuity with the clear visor was approximately 20/20, while with the sun visor it was approximately 20/30. The FV-7 visors, which is designed to be used as a combination sun/ALEP visor, performed essentially the same as the USAF sun visor. These results indicate that neither the dye technology used in the ALEP visors nor the selective filtering of visual spectrum for laser protection is unique and, therefore, may not adversely affect contrast acuity. This is of course assuming that the other optical properties such as haze and distortion are comparable to the sun visor.

In summary, the effects of haze in the ALEP visors appears to be minor for high contrast targets, even in the presence of glare near the line of sight. However, for low contrast targets our results suggest that the haze in visors may reduce visual performance to a degree not acceptable to some aircrew members. In addition, the presence of glare near the line of sight may enhance the negative effects of haze on vision. In this sense, the results of our study, do support the results of the EOA flight tests. The level of haze in the ALEP visors that were used during the EOA flight tests and in this study may reduce visual performance for low contrast targets to a degree unacceptable to some aircrew members. It should be pointed out, however, that the ALEP visors tested in this study represented developmental samples and that the overall results from the EOA flight tests were highly successful in terms of aircrew acceptance and mission performance.

In conclusion, our results suggest that the haze in helmet visor may reduce the aircrew's ability to either detect or identify low contrast targets. Given the finding that glare may enhance the effects of haze and the fact that the ALEP visors are designed for use where a laser beam as a glare source is a real possibility, we recommend that in

production ALEP helmet visors PLT be maximized as much as possible and that the current USAF specification of 2.0% for haze not be relaxed.

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